IBM No. 65-928-63

SUMMARY OF RESULTS OF ENGINEERING RESEARCH PROGRAM FOR MANNED EARTH-ORBITAL MISSIONS

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FEDERAL SYSTEMS DIVISION
SPACE GUIDANCE CENTER
Owego, New York

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

[redacted]

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FOREWORD

The subject study, "Engineering Research Experiments Program for Earth-Orbital Missions," was conducted under Contract NAS 1-4667 by International Business Machines Corporation, Federal Systems Division, and its major Subcontractor, Douglas Aircraft Company, Space and Missile Systems Division. Other subcontracts were awarded to Bell Aerosystems Corporation, and Environmental Research Associates.

The results of the study are presented in four reports:

X65-20825 CV-67549

- "Summary of Results of Engineering Research Experiments Program for Manned Earth-Orbital Missions, "IBM Report No. 65-928-63, August 1965.

Temp 97853

- "Derivation of a Comprehensive Engineering Experiment Program for Manned Earth-Orbital Missions, " IBM Report No. 65-928-64, August 1965.

X65-20907 CV-67525

- "Analysis and Preliminary Design of Engineering Experiments for Manned Earth-Orbital Missions, " IBM Report No. 65-928-65, August 1965.

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- "Allocation of Scarce Resources Aboard an Orbital Laboratory, " IBM Report No. 65-928-66, August 1965.

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INTRODUCTION

This study relates to the current examination of concepts being conducted by the National Aeronautics and Space Administration for the purpose of designing an earth-orbiting research laboratory (ORL). When the ideas behind a manned ORL are transformed into flight systems, the laboratory will be used for performing manned experiments in space. These experiments are necessary for assuring the success of various space missions planned or contemplated for the purpose of finding out more about the moon, the nearer planets, and space itself. To obtain the maximum usefulness from an ORL, the future space missions must be reviewed to discover where technical information is lacking, and how this missing knowledge affects the success of the mission. Because biomedical and scientific experiments are being examined in depth by others, the study described herein was concerned with evaluating the need for further engineering data. The experiments proposed as the result of this study relate principally to equipment design problems, and to the definition of performance requirements for the flight hardware.

The forthcoming ORL program marks the transition from the era in which man has preliminarily explored space, to the age during which man will purposefully use space for his economic and social benefit.

Figure 1 shows the principal objectives of the manned earth-orbital experiment program. Thirteen fundamental scientific/technical areas are shown. These represent potential user-oriented applications, and constitute a logical basis for analysis of requirements. This orientation provides for correlating the participation of the scientific and technical community in detailing, conducting, and applying the results of the experiment program. The engineering experiments that are the subject of this study fall within three closely related divisions of the major category, Support for Space Operations.

- Advanced Technology and Supporting Research. - Experiments within this group are intended to extend technical knowledge over a broad spectrum of engineering science. These experiments will delineate and codify engineering principles that require reformulation for applicability in the space environment. The experiments are defined to verify the engineering principles, and to explore subsystem interactions.

- Operations Techniques and Advanced Mission Spacecraft Subsystems. - This group contains experiments involving those systems and subsystems associated with the basic spacecraft, and the systems that support the well-being of astronauts.

- <u>Extra-Vehicular Engineering Activities</u>. - Experiments concerned with this subject involve those mission-configured equipments, techniques, and procedures that are associated with manned extra-vehicular technical activities.

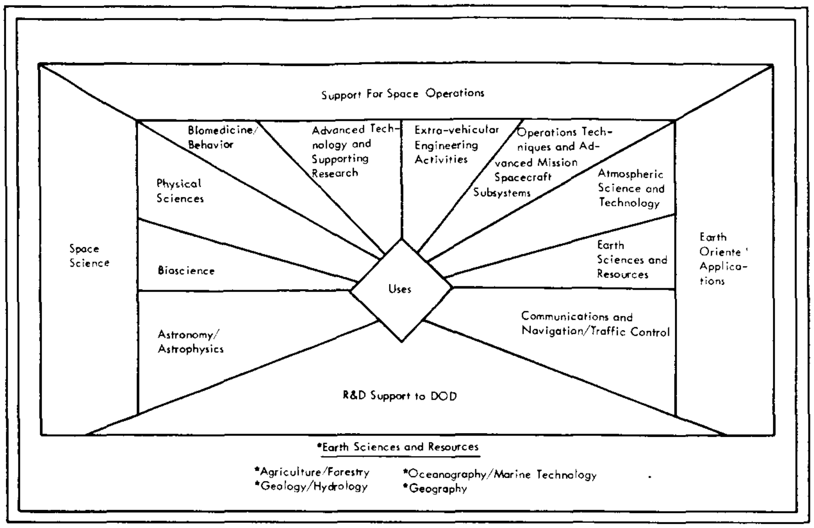

Figure 1. Major Scientific/Technical Areas of Interest for the MORL Experiment Program

The engineering experiments are concerned with gathering basic design data, and with the validation and qualification of procedures and mission-configured flight-prototype hardware. These experiments implicitly relate to all other objectives of the total experiment program, because they will provide the fundamental knowledge required to build and operate the spacecraft systems of the future.

Experiments intended to add to the existing space engineering knowledge are being conducted in ground, airborne, and unmanned space facilities. Current manned space flights, although not designed primarily for gathering engineering data, will contribute significantly to space engineering technology. But, for man to begin to purposefully exploit space, experiments must be conducted in a fully integrated program designed expressly for deriving information in which a high degree of confidence can be placed. Only in this manner can the overall objectives of the multi-phase ORL program be achieved.

STUDY OBJECTIVES

The first objective of this study was to derive a soundly based, comprehensive, earth-orbital engineering experiment program that will provide the technical knowledge necessary for success of the presently planned and anticipated future missions of the national space program. The derived experiment program should categorize, and show the relative importance (or priority) of, the proposed experiments, and indicate their relationship to the requirements of the overall US space program.

The second purpose of the study was to preliminarily analyze and design eight ORL experiments that concern key problems discovered during the derivation of the engineering experiment program. These experiments are to be comprehensively designed so that their development can proceed from the "conceptual" to the "proven feasible" stage. This necessitates establishing a definite set of objectives; and analyzing apparatus and data requirements, and the requirements imposed on the space laboratory.

Finally, the study was to establish the criteria needed by the spacecraft designer, experiment integrator, and the experiment designer to solve the complex problems of allocating the spacecraft resources to the experiment requirements. This includes the information necessary to determine the best possible trade-offs of one resource for another.

STUDY LIMITATIONS

The following represent the approximate engineering effort applied to this study:

- Derivation of Engineering Experiment Program — 6000 hours
- Preliminary Design of Experiments — 6000 hours
- Allocation of Resources Criteria — 600 hours

The limitations of consequence were:

- The study was restricted to consideration of experiments to be performed in earth orbit aboard either an AES or MORL. Consequently, the experiment program does not include experiments to be performed aboard a lunar orbital mission, interplanetary missions, or aboard unmanned earth satellites.
- Engineering problems concerned with either lunar-orbital vehicles or lunar surface vehicles were, by direction, excluded from the study.
- Problems associated with nuclear propulsion systems and electric power generation were restricted to unclassified data.

- Only eight preliminary experiment designs were undertaken in order to provide the depth required. Consequently, the design of equally worthy experiments had to be postponed.

- Application of the resource allocation techniques was limited to conceptual items because parametric and cost data were not available for the experiments, or for the spacecraft designs.

METHOD OF APPROACH, AND PRINCIPAL ASSUMPTIONS

DERIVATION OF A COMPREHENSIVE ENGINEERING EXPERIMENT PROGRAM

The engineering experiment program was derived in a logical and orderly fashion. Future planned and contemplated NASA space missions were examined, and four key missions or programs identified as encompassing the major technological problems associated with the entire national space program. From detailed analysis of these engineering problems, engineering experiments, and finally the engineering experiment program were obtained.

Figure 2 illustrates the processes used to derive the engineering experiment program. Identified in the figure are the four selected key missions and programs.

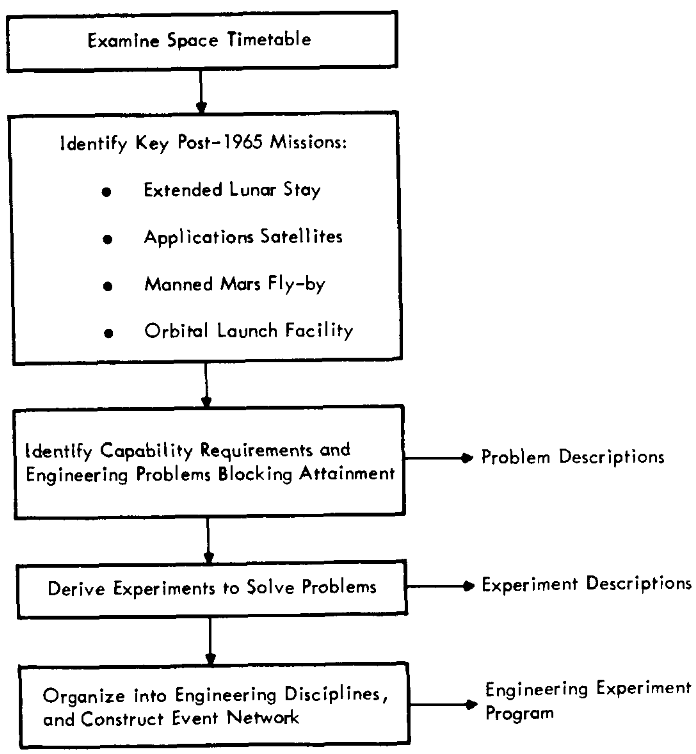

Figure 2. Derivation of Engineering Experiment Program

NASA and contractor reports (to June 1965) relating to the key missions were studied to determine the engineering problems preventing mission achievement. Problems were cataloged using forms such as shown in Figure 3. Individual experiments were conceived to provide basic data for the engineering solutions of these problems, or to test techniques and equipment that could resolve the unknowns in the problem definition. Reference sources for experiment descriptions were NASA studies, studies performed by IBM, or related contractual studies. Wherever additional information was necessary for complete coverage of the problem area, new experiments were derived.

These experiments were then formulated into the engineering experiment program. The experience or knowledge needed before performing each experiment was identified, and an event network constructed to show each experiment as an event. This PERT-like network forms the basis of the experiment program by showing the relationship of each experiment to the others, and the order (or priority) in which they should be conducted.

EXPERIMENT PRELIMINARY DESIGN

Eight experiments were selected for preliminary analysis and design from the engineering experiment program just described. IBM considers these experiments highly desirable candidates for early AES flights:

- Retrieval of a Dormant Satellite for Materials Investigation
- Inspection of Satellite Materials by Remote Sensing
- Evaluation of a Space Hangar for a Satellite
- Removal of Satellite Components
- Calibration of a Low-G Sensor
- Long-Boom Dynamics
- Ullage Control for Fuel Transfer
- Extra-vehicular Patching Techniques

Area 11. Mission Support

Area 10. Emergency Procedure

Area 9. Multiple-Vehicle and Extravehicular Operations

Area 8. Life Support

Area 7. Environmental Control

Area 6. Propulsion

Area 5. Electric Power

Area 4. Navigation

Area 3. Stabilization and Control

Area 2. Communications

Area 1. Space Effects on Materials and Structures

Problem/Mission Phase Matrix

Problem Number	Problem Title	ORL Recom.	Lunar Exploration: Activation	Lunar Exploration: Operation	Lunar Exploration: Exploration	Lunar Exploration: Surface Exper.	Lunar Exploration: Orbital Obs.	Orbital Launch: Orbital Transfer	Orbital Launch: Rendezvous	Orbital Launch: Docking	Orbital Launch: Crew Transfer	Orbital Launch: Cargo Transfer	Orbital Launch: Fuel Transfer	Orbital Launch: Servicing	Orbital Launch: Maintenance	Orbital Launch: Checkout
1.1	Degradation of Transmission Lines	Yes		x	x	x			x		x	x	x	x	x	x
1.2	Interplanetry and Near-Martian Environments	No														
1.3	Overboard Gases	Yes							x		x	x	x	x	x	x
1.4	Electrical Connectors	Yes	x	x	x	x	x			x	x	x	x		x	x
1.5	Zero-G Condensing and Liquid Dynamics in Power Plants	Yes														
1.6	Degradation of Solar Panels	Yes		x		x			x	x	x	x	x	x	x	x
1.7	Earth Re-entry	No														
1.8	Effects of Hypervelocity Particles on Materials	Yes	x	x	x	x	x		x	x	x	x	x	x	x	x
1.9	Meteoroid Flux	No							x	x	x	x	x	x	x	x
1.10	Lunar Radiation Environment	No	x	x	x	x										
1.12	Degradation of Solar Energy Collector	Yes		x												
1.13	Effect of Space Environment on Optical Materials	Yes							x	x	x	x	x	x	x	x
1.14	Bearings	Yes	x	x	x	x	x		x	x	x	x	x	x	x	

Figure 3. Problem/Mission Phase Matrix

n Phases

		Mars Fly-by									Application Satellites							
Countdown	Launch	Experiments	Life Supp. Env. Con.	Prop. Store	Nav. and Guid.	Attitude Control	Communication	Electric Power	Earth Re-entry	Experiments	Rad. Shielding	Env. Cont.	Nav. and Guid.	Attitude Control	Communication	Electric Power	Image Forming Data Collection Eq.	Non-Image Forming Data Coll. Eq.
		x	x				x	x		x					x	x		
			x	x	x	x	x	x	x	x	x							
		x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
		x					x	x	x	x					x	x	x	x
								x								x		
		x														x		
									x									
		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		x										x	x	x	x	x	x	x
								x										
		x			x	x		x	x	x			x	x		x	x	
		x	x		x	x	x	x	x	x		x	x	x	x	x	x	x

The first four experiments are closely related, and investigate several of the problems associated with the manned retrieval of a satellite for evaluating materials that have been exposed to the space environments for several years. The low-G sensor experiment was chosen to provide, at an early date, an instrument sufficiently accurate for the design of guidance and stabilization systems for advanced spacecraft. The long-boom dynamics and the ullage control experiments are steps toward large-scale space operations. The long boom can provide the means by which man handles massive structures in space, and ullage control is vital to in-space refueling operations. The successful determination extra-vehicular repair techniques enhances the astronauts' safety during long-term missions.

Key factors in each experiment were selected for analysis to find out if the experiment could be transported from the "conceptual" to the "feasible" phase of design. Wherever applicable, these analyses were quantitative and mathematical in nature. In every experiment, IBM found that additional factors beyond the scope of this contract remained to be analyzed before the feasibility of the experiment could be conclusively demonstrated.

ALLOCATION OF RESOURCES IN AN ORBITAL LABORATORY

The similarity between the allocation of resources in an ORL and the allocation of jobs in a manufacturing facility was recognized, and the operations-research techniques developed for the latter were applied to the ORL problem. Whereas the manufacturer has limited resources to apply for meeting some demands, the ORL designer has limited power, crew time, weight, etc., available to meet the demands of individual experiments. By considering each of these resource parameters as a vector and applying the proper OR techniques, it may be possible to increase the efficiency of allocating laboratory resources.

BASIC DATA GENERATED, AND SIGNIFICANT RESULTS

DERIVATION OF A COMPREHENSIVE ENGINEERING EXPERIMENT PROGRAM

The data generated in this portion of the study basically consists of the three outputs shown in Figure 2: the engineering problem descriptions, the engineering experiment descriptions, and the engineering experiment program. These data are too voluminous for inclusion here, but the scope of this work can be appreciated from the titles of the problem descriptions and experiment descriptions listed in Tables 1 and 2, respectively. Figure 4 shows a section of the engineering experiment program event network dealing with materials and structures. The four major symbols define the different types of experiments that must be defined for such a program:

- Basic experiments that must first be conducted on earth

Table 1

TITLES OF ENGINEERING PROBLEM DESCRIPTIONS

APPENDIX A — ENGINEERING PROBLEM DESCRIPTIONS

EFFECTS OF THE SPACE ENVIRONMENT ON MATERIALS AND STRUCTURES

1.1 Degradation of Transmission Lines
1.2 Interplanetary and Near-Mars Environments
1.3 Overboard Gases
1.4 Electrical Connectors
1.5 Zero-G Condensing and Liquid Dynamics in Power Plants
1.6 Degradation of Solar Panels
1.7 Earth Re-entry
1.8 Effects of Hypervelocity Particles on Materials
1.9 Meteoroid Flux
1.10 Lunar Radiation Environment
1.12 Degradation of Solar-Energy Collectors
1.13 Effect of the Space Environment on Optical Materials
1.14 Bearings
1.15 High-Temperature and Vacuum Characteristics of Materials
1.16 Hard-Vacuum Metal Fatigue
1.17 Space Environment Effects on Plastics and Elastomers
1.18 Thermal Cycle Effects — Lunar Surface
1.19 Cold Welding
1.20 Large Structure Inflation
1.21 Vacuum Lubricants

COMMUNICATIONS

2.1 Data Character
2.2 Narrow-Beam Acquisition and Tracking for Laser Communications
2.3 Electromagnetic Background Character
2.4 Electromagnetic Propagation Parameters
2.5 Low-Frequency Lunar Communication System
2.6 Space Antennas
2.7 Degradation of Communications Equipment
2.8 Radio Frequency Interference

STABILIZATION AND CONTROL

3.1 Valves for Reaction Control Systems (RCS)
3.2 Combustion Chamber Cyclic Endurance
3.3 Reaction Control System Propellant Ignition
3.4 Propellant Shock Sensitivity
3.5 Control-Moment Gyros
3.6 Reaction Control System Propellant Expulsion
3.7 Centrifuge Mass Balance
3.8 Gravity Gradient Stabilization
3.9 Fine Pointing and Stabilization in Unmanned Satellites
3.10 Fine Pointing and Stabilization in Manned Vehicles
3.11 Magnetic Torquers for Vehicle Attitude Stabilization
3.12 Image Motion
3.13 Passive Satellite Stationkeeping
3.14 Autonomous Pointing
3.15 Dynamics of External Erectable Booms

NAVIGATION

4.1 Autonomous Navigation Techniques
4.2 Sensor Alignment and Calibration
4.3 Interferometer Potential
4.4 Refraction Correlation.
4.5 Star Signature Identification
4.6 Surface Feature Identification and Tracking
4.7 Lunar Surface Navigation
4.8 Navigation Sensor Performance
4.10 Earth Horizon Characterization
4.11 Tracking Station Calibration
4.12 Near-Earth Space Force Field

ELECTRICAL POWER

5.1 Use of Slip-rings for Power Transmittal
5.2 Development of Fuel Cells
5.3 Isotope Brayton-Cycle Power Source
5.4 Subcritical Storage of Cryogenic Fluids Under Zero Gravity

PROPULSION

6.1 Propellant Storage
6.2 Fuel Transfer
6.3 Behavior of Fuel and/or Oxidizer in Vehicle Tanks under Varying Gravity Conditions
6.4 Fuel Storage on the Lunar Surface

ENVIRONMENTAL CONTROL

7.1 Use of Wicking Materials for Water Removal
7.2 Fabrication and Operation of Space Radiators
7.3 Effects of the Space Environment on Thermal Coatings
7.4 Thermal Control for the Space Vehicle
7.5 Thermal Control for the Lunar Surface Shelter

LIFE SUPPORT (UNIQUE TO LIFE)

8.1 Waste Disposal in Space
8.2 Waste Disposal on the Lunar Surface
8.3 Waste Removal from Chemical Power Sources
8.4 Personal Hygiene
8.5 Carbon Dioxide Removal
8.6 Food, Long-Term Use
8.7 Spacesuits and Associated Life Support Systems
8.8 Artificial Gravity System
8.9 Trace Contaminant Control
8.10 Determination of Weight in Zero-G Environment
8.11 Zero-Gravity Laundry
8.12 Spacecraft Atmosphere Selection
8.13 Physical Fitness Procedures
8.14 Evaluation of Pure Oxygen Atmosphere
8.15 Sedimentation Studies

MULTIPLE AND EXTRA-VEHICULAR OPERATIONS

9.1 Vehicle Attachment and Connection
9.2 Cooperative Rendezvous
9.3 Astronaut Restraint
9.4 Tools and Tool Restraint
9.5 Extra-vehicular Maintenance
9.6 Retrieval of Tethered Astronauts
9.7 Internal Maintenance
9.8 Personnel and Cargo Transfer
9.9 Assembly of Structures in Space
9.10 Orbital Refueling of Power and Propulsion Sources
9.11 Umbilical Lines
9.12 Extra-vehicular Locomotion/Astronaut Extra-vehicular Propulsion
9.13 Docking
9.14 Non-cooperative Rendezvous
9.15 Area Fuel Transfer
9.16 Welding, Soldering, and Joining
9.17 Large Structure Manipulation
9.18 Extra-vehicular Astronaut Control

EMERGENCY PROCEDURES

10.1 Leakage Detection
10.2 Fire Propagation and Control
10.3 Self-sealing Techniques
10.4 Extra-vehicular Rescue

MISSION SUPPORT

11.1 Disposal of Nuclear Power Sources
11.2 Multisensor Imaging Techniques and Verification of Observation
11.3 Atmospheric Radiation Model Verification
11.4 Acceptability of Existing Multispectral Sensors for In-space Environment
11.5 Lunar Surface and Subsurface Analysis
11.6 Low Residual Magnetic Fields
11.7 Effect of Boost Phase on Instrument Alignment and Calibration
11.8 Film Developing and Processing

Table 2

TITLES OF ENGINEERING EXPERIMENT DESCRIPTIONS

APPENDIX B — ENGINEERING EXPERIMENT DESCRIPTIONS

SPACE EFFECTS ON MATERIALS AND STRUCTURES

1.1 Measurements of Spacecraft Local External Atmosphere
1.2 Manned Spacecraft Drag
1.3 Measurements of Jet Flown in a Vacuum
1.4 Plume Impingement Study
1.5 Sublimation and Condensation of Metals
1.6 Evaluation of Meteoroid Damage
1.7 Measurements of Solar Absorptivity and Thermal Emissivity of Thermal-Control Coatings
1.8 Radiation Effects on Semiconductors and Photovoltaic Cells
1.9 Effects of Radiation on Space Materials
1.10 Exposure of Optical Materials to the Space Environment
1.11 Long-Term Effects of Space Environment on Charring Ablators for Space Vehicles and Rocket Nozzles
1.12 Evaluation of Elastomers in Space
1.13 Fracture and Fatigue Crack Growth of Metals in a Space Environment
1.14 Cold Welding
1.15 Dynamics and Space Environment Effects on Long Booms
1.16 Bearing Lubrication in Zero Gravity
1.17 Friction Coefficients in a Space Environment

COMMUNICATIONS AND ELECTRONIC MISSION SUPPORT

2.1 Alignment and Calibration of a Large Antenna
2.2 Monitoring and Compensation of a Large Antenna
2.3 Connector Evaluation, With Retrieval
2.4 Transmission Line Verification
2.5 Verification of Degradation of Communication Equipment
2.7 Verification of Alignment and Calibration for Electronics
2.8 Electromagnetic Background Measurement
2.10 Communication Interference from Power and Propulsion Systems
2.11 Space Communication by Centimeter Waves
2.12A Laser Communication (Earth to Space, and Space to Earth)
2.12B Laser Communication (space to space)
2.13 Orbital Verification of a Communication System for Manned Mars Fly-by

PROPULSION AND REACTION CONTROL SYSTEM

3.1 Flight Test of Solid-Core Reactor, With Retrieval
3.2 Performance and Life Test of Small Ion Engine, With Retrieval
3.3 Assembly and Test of Clustered Ion Engines
3.4 Performance and Life Test of Electrothermal Engine, With Retrieval
3.5 Performance and Life Test of POODLE, With Retrieval
3.6 Solar Sail Orbital Test, With Retrieval
3.7 Orbital Test of Passive Station Keeper, With Retrieval
3.9 Propellant Settling Techniques
3.10 Fuel Quantity Measurement
3.11 Subcritical Storage of Cryogenic Propellant, With Heat Pump
3.12 Sunshade Experiment

GUIDANCE AND NAVIGATION

4.1 Multispectral Determination of Earth Horizon Characteristics
4.2 Verification of Lens Protective Devices
4.3 Determination of Performance Statistics of Navigation Sensors
4.4 Evaluation of Astronauts, Feature Recognition, Fix Taking, and Tracking Capabilities Using a Low-Power, Gimbaled Telescope
4.5 Photographic Tests
4.8 Performance Tests of Navigation with Simple Instruments
4.12 Evaluation of Earth-Star Occultation Measurement Techniques
4.13 Evaluate Methods or Equipment for Determining the Centroid of the Sun, Moon, or Planets
4.16 Electromagnetic Propagation Measurements
4.17 Refraction Correlation
4.19 Evaluation and Comparison of Autonomous Navigation Techniques
4.20 Acceptability of Multispectral Sensors
4.24A Verification and Evaluation of Manual or Semiautomatic Alignment of Optical Equipment to Related Sensors or Detectors
4.24B Verification and Evaluation of Manual Procedures for Aligning, Calibrating, and Adjusting Optical Systems
4.24C Verification and Evaluation of Automatic Alignment of Electro-optical Equipment and sensors
4.25 Evaluation of Performance of Stabilization Sensors
4.26 Flight Verification of an Advanced Attitude Control System
4.27 Fine Star Pointing
4.29A Stabilized Platform Subsystem Development
4.29B Flight Verification of a Stabilized Platform
4.30A Navigation Fixing by Manual Sighting on Other Satellites
4.30B Navigation Fixing by Automatic Acquisition and Tracking of Satellites
4.31 Vibration Effects Caused by an Eccentric Mass on a Centrifuge
4.32 Momentum Exchange Method of Determining Mass in a Zero-Gravity Environment
4.33A Orbital Test of BOLO Deployment, Dynamics, and Retraction
4.33B Space Station Rotation for Artificial Gravity
4.34 Measurement of Disturbances Due to Crew Motion and Other Sources
4.36 Evaluation of Automatic Earth-Feature Sensors
4.37 Calibration and Test of High Performance Gyroscopes
4.38 Evaluation of Low-Gravity Accelerometers
4.39 Test of Gravity Gradient Attitude Sensing System Using Low-Gravity Accelerometers
4.40 Stabilization by Solar Pressure
4.41 Determination of Vehicle Mass, Centroid and Moments and Products of Inertia
4.42 Orbital Test of Control-Moment Gyros

ELECTRICAL POWER

5.1 Solar Collector Power System
5.2 Boiler-Condenser Experiment (NaK)
5.3 Verification of Isotope Power Source by Retrieval

LIFE SUPPORT AND ENVIRONMENTAL CONTROL

6.1 Qualification of On-board Centrifuge
6.2 Evaluation of Physical-Fitness Procedures
6.3 Toxicological Studies of Respiratory Cases in Manned Spacecraft
6.4 Qualification of Two-Component Spacecraft Atmosphere Systems
6.5 Evaluation of Advanced Space Suit Assemblies
6.6 Evaluation of Oxygen Recovery System
6.7 Sedimentation Studies in Zero Gravity
6.8 Fluid Management Techniques for Life Support System
6.9 Food Storage and Preparation
6.10 Waste Disposal in Space
6.11 Evaluation of Equipment and Procedures for Personal Hygiene
6.12 Response of a Partially Filled Tank in Zero-Gravity Due to Translation Loads
6.13 Liquid Response to Tank Rotation
6.14 Fluid Settling Techniques
6.15 Static and Motion Tests of Interface Phenomena
6.16 Storage of Cryogenic Fluids in Space
6.17 Orbital Test of Super-insulated Tank
6.18 Convective Heat Transfer at Zero Gravity
6.19 Operation of Space Radiator in Earth Orbit
6.20 Tests of Self-Sealing Structures
6.21 Space Vehicle Thermal Equilibrium Study
6.22 Ionizing Radiation Measurements
6.23 Activation Measurements (Induced Radioactivity)
6.24 Internal Laboratory Spacecraft Environment — Noise and Vibration Levels

MULTI-VEHICLE AND EXTRA-VEHICULAR ACTIVITIES

7.1 Extra-vehicular Adhesives and Patching Methods
7.2 Feasibility of Performing Welding Operations
7.3 Force-producing Capabilities of the Astronaut in Zero Gravity
7.4 Tools and Tool Restraints
7.5 Umbilical Lines and Tethers
7.6 Self-Rotation and Orientation Stability of the Astronaut in Zero Gravity
7.7 Astronaut Extra-vehicular Maneuvering Unit (Back Panel)
7.8 Emergency Airlock and Shelter
7.9 Control and Maneuver Capability of Tethered Extra-vehicular Workers
7.10 Assembly and Repair
7.11A Erection of Large Space Structures
7.11B Erection of Enclosing Structures in Space
7.11C Deployment of Inflatable Structures
7.12 Manned Maneuvering Unit
7.13 Remote Maneuvering Unit
7.14 Docking of Two Space Vehicles in Earth Orbit
7.15 Personnel and Cargo Transfer
7.16 Cryogenic Propellant Transfer in Earth Orbit
7.17A Detection and Tracking of Satellites from a Spacecraft for Purposes of Retrieval
7.17B Uncooperative Rendezvous
7.18 Extra-vehicular Rescue
7.19 Propagation and Control of Fire in Zero, or Reduced-Gravity Environment
7.20 Extra-vehicular Leak Detector
7.21 Capture of Satellites
7.22 Illumination
7.23 Removal of Components from a Captured Satellite
7.24 Co-orbital Inspection of Satellite
7.25 Enclosure of Satellite in a Hangar

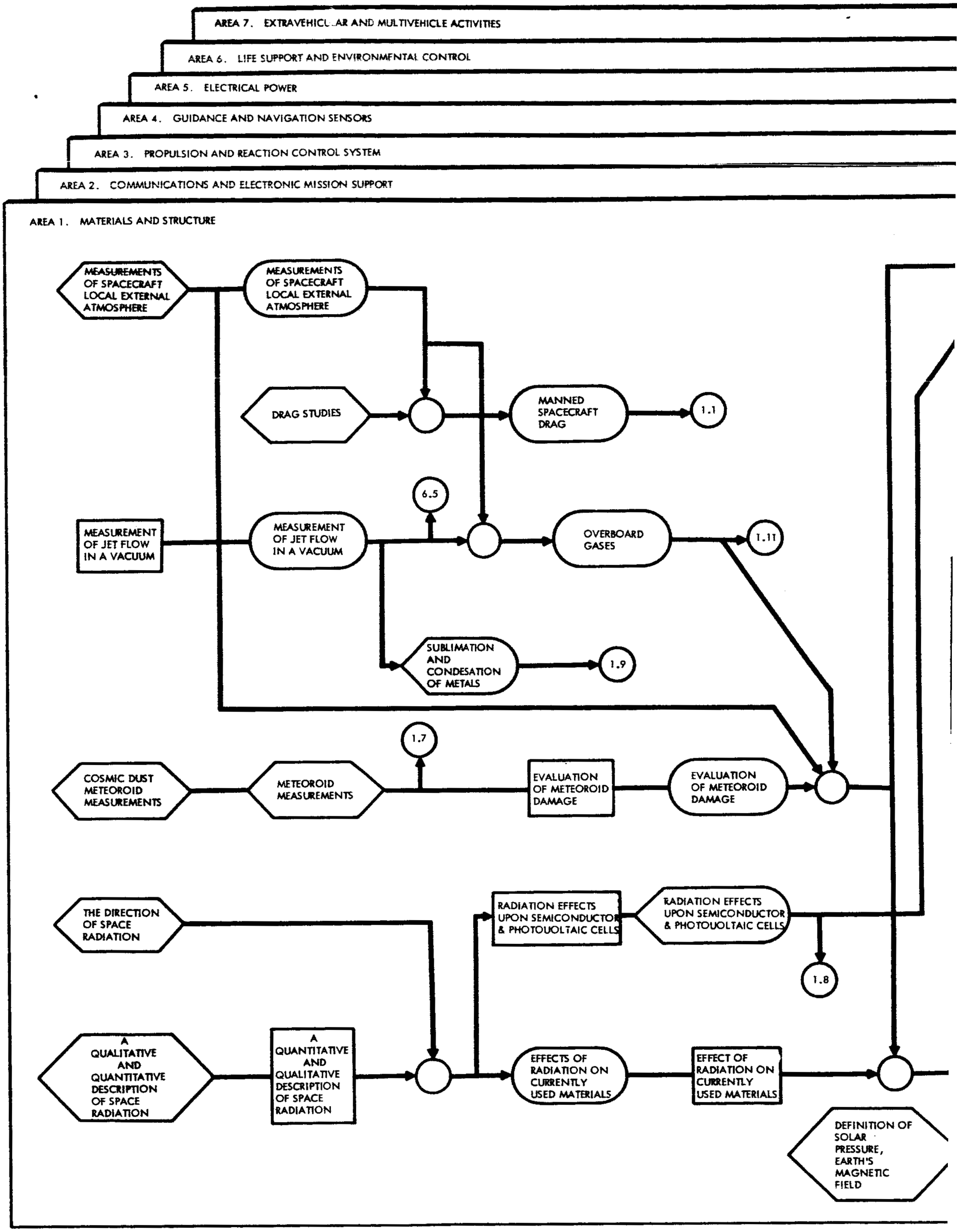

Figure 4. Partial Event Network for the Engineering Experiment Program

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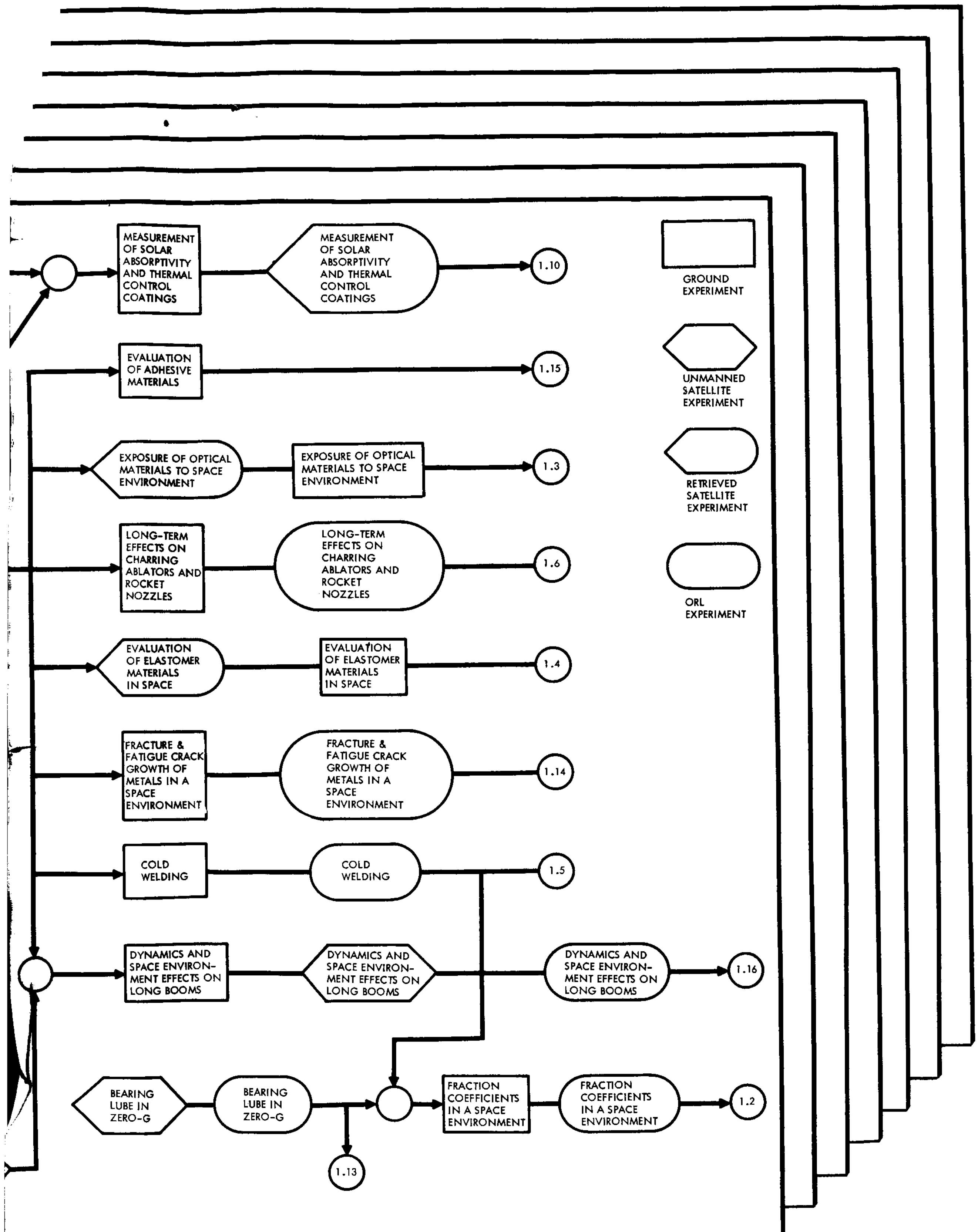
MEASUREMENT OF SOLAR ABSORPTIVITY AND THERMAL CONTROL COATINGS
MEASUREMENT OF SOLAR ABSORPTIVITY AND THERMAL CONTROL COATINGS
1.10
EVALUATION OF ADHESIVE MATERIALS
1.15
EXPOSURE OF OPTICAL MATERIALS TO SPACE ENVIRONMENT
EXPOSURE OF OPTICAL MATERIALS TO SPACE ENVIRONMENT
1.3
LONG-TERM EFFECTS ON CHARRING ABLATORS AND ROCKET NOZZLES
LONG-TERM EFFECTS ON CHARRING ABLATORS AND ROCKET NOZZLES
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EVALUATION OF ELASTOMER MATERIALS IN SPACE
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FRACTURE & FATIGUE CRACK GROWTH OF METALS IN A SPACE ENVIRONMENT
FRACTURE & FATIGUE CRACK GROWTH OF METALS IN A SPACE ENVIRONMENT
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COLD WELDING
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DYNAMICS AND SPACE ENVIRON-MENT EFFECTS ON LONG BOOMS
DYNAMICS AND SPACE ENVIRON-MENT EFFECTS ON LONG BOOMS
1.16
BEARING LUBE IN ZERO-G
BEARING LUBE IN ZERO-G
1.13
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FRACTION COEFFICIENTS IN A SPACE ENVIRONMENT
1.2
GROUND EXPERIMENT
UNMANNED SATELLITE EXPERIMENT
RETRIEVED SATELLITE EXPERIMENT
ORL EXPERIMENT

2

- Experiments best performed using an unmanned satellite (due to economy, safety, etc.)
- Experiments that require a manned ORL
- Experiments that require an ORL with the capability to retrieve objects in orbit.

The arrows or lines leading into each experiment define the events that must be completed before the experiment in a particular box can be conducted. Lines leading from an experiment box point to the follow-on experiments or capabilities obtained. Note, however, there are no times associated with these lines. Thus, this network only orders the sequence of the program; it does not schedule the program.

Similar networks were derived for six other experiment areas: communications and electronics, propulsion and reaction control systems, guidance and navigation, electrical power, life support and environmental control, and extra-vehicular and multi-vehicular activities. The full results are presented in "Derivation of a Comprehensive Engineering Experiment Program for Manned Earth-Orbital Missions," IBM Report No. 65-928-64, August 1965.

The significance of the work done for this task area is twofold. First is the development and application of methods that, in an orderly and logical manner, identify the experimentation necessary to achieve specific mission goals. The applicability of this technique extends beyond the bounds of engineering experiments to the biomedical/behavioral and scientific experiments as well. The use of a PERT-like event network to show the proper sequence of experiments, and their interrelationships, provides valuable assistance in controlling an experiment program of the immense scope expected for the ORL. Such networks permit rapid evaluation of the applicability of proposed new experiments.

The second item of significance is that the program provided by this study can serve as the basic instrument for defining the initial experiments for AES flights.

PRELIMINARY DESIGN OF EXPERIMENTS

Retrieval Experiments

Future NASA space missions require increased knowledge of the long-term effects of the space environment on the materials used for spacecrafts and their components. There are enough unknowns that designers cannot be sure of the reliable operation of the space systems and subsystems they produce. Much of the difficulty results from the environment being inadequately defined. Thus, the behavior of critical elements and materials in this environment cannot be confidently predicted. One of the best ways to obtain precise engineering data is to observe what has actually happened to the materials in satellites that have been orbiting the earth for several years. IBM regards the recovery of a satellite by an AES as a feasible means of obtaining materials specimens for a comprehensive evaluation of the manner in which these have been affected by the various aspects of the space environment. This led to the definition of four experiments related to satellite retrieval, and to the preliminary design and analysis of those experiments. A brief description of the experiments follows.

Experiment 1, "Retrieval of a Dormant Satellite for Materials Investigation." — This experiment establishes the feasibility of the recovery technique. Eight US satellites were chosen as likely candidates for retrieval. Each of these satellites contain materials, the evaluation of which would provide very worthwhile data about long-term space effects. The candidates are: Vanguard 1; Explorer 7, 16, and 26; Telstar 1 and 2; Tiros; OGO 1; and OSO 1. Of these, OSO 1 is proposed as a best choice for the first AES recovery, for the following reasons:

- Favorable inclination: The 32.8° inclination of OSO 1 permits a coplanar launch that is well within the range safety limits at Cape Kennedy.
- Small ΔV requirement: The 590/544-km altitude requires a ΔV of only 740 feet/second, which is well within the capability of the LEM-Apollo.
- Favorable launch opportunities: For launch of an ORL into an orbit coplanar with OSO 1, windows several hours long occur daily. Seven times a year, for about two weeks at a time, these windows occur at the right time of day for safe manned launch.
- Low radiation hazard: The OSO-1 orbit is in a radiation field of less than 2 rads/day.
- Long exposure to environment: The satellite was launched in 1962.
- Available materials: There are many different materials and subsystems worthy of investigation aboard the OSO 1.

Experiment 2, "Inspection of Satellite Materials by Remote Sensing." — The feasibility of performing this experiment has been established. Although a materials evaluation should have a more detailed analysis of requirements than performed, a set of desirable measurements was postulated. From these, the preliminary design of a remote sensing system was determined. This system consists primarily of (1) a visual/photo-optical subsystem, (2) an infrared thermograph, and (3) a grating spectrometer.

The LEM ascent stage can accommodate the necessary operational requirements for co-orbital inspection when supplemented with a stationkeeping radar and a TV camera — if this stage also has the digital-computer interface, displays, and controls modified to accept inputs from the radar and camera; and if the computer program is similarly revised. The distance from which observations are made will range from 50 to 10 feet. Approximately four hours is required to make the anticipated observations. The three major observation sensors, their measurement class, and their weight and volume are given in Table 3.

Table 3

OBSERVATION SENSORS FOR CO-ORBITAL INSPECTION

Measurement	Primary Observation Sensors		
	Visual Photo/Optical Sensor	Infrared Thermograph	Grating Spectrometer
Spin & Tumbling Characteristics	P		
Micrometeoroid Damage (punctures, erosion, shattering)	P	S	S
Surface Conditions (coating, peeling, blistering)	P	S	S
Fracture	P	P	
Structural & Shape Deterioration	P		
Emissivity, Absorptivity		S	P
Reflectivity	S	S	P
Temperature Profile		P	P
Weight (pounds)	72	50	25
Volume (cubic feet)	2.8	0.95	2.0
P = primary sensor S = secondary sensor			

Experiment 2 does not appear to have any critical problem areas in the sense of requiring engineering or scientific breakthroughs, but the engineering and support efforts are considerable. The LEM vehicle must be modified to incorporate the inspection sensor, the sensor itself must be designed and built, and the guidance rules must be modified for the new mission using the LEM ascent stage as the inspection vehicle.

Experiment 3, "Evaluation of a Space Hangar for a Satellite." — This experiment establishes the feasibility of designing a semi-rigid space hangar compatible with the AES, or the MORL space station. Design requirements, developed for enclosing a Nimbus-sized satellite, are:

Weight	182 pounds
Volume (folded)	200 cubic feet
Diameter (deployed)	10 feet
Length (deployed)	15 feet
Skin material	Neoprene, butyl, or silicone rubber
Pressure/atmosphere	5 psi/oxygen + inert gas

The experiment discussion (IBM Report No. 65-928-65, Part I) shows that such a hangar provides a desirable sheltered work area in which astronauts can perform exacting tasks, such as component removal. The pressurized atmosphere gives the astronaut greater mobility in his space suit than does free space. The controlled temperature, lighting, and work platforms greatly enhance man's ability to do useful work in space.

The most significant potential problem confronting the successful completion of Experiment 3 appears to be the limit of human capabilities in space. Despite the use of an auxiliary propulsion unit, the astronaut's coordination, reaction, alertness, and ability to do work are hindered not only by his weightlessness and the restraint of his pressure suit but also by the forces that tend to move the satellite from the hangar and its ultimate tie-down points. Secondary problems include proper assessment and control of the potential dangers of space. These include hangar puncture, space suit leaks, failure of the oxygen-supply umbilical, and inadvertent injury to the astronaut.

Experiment 4, "Removal of Satellite Components." — This experiment determines the feasibility of removing selected assemblies from a retrieved satellite, once it is secured in a space hangar. Also established are the methods an astronaut would use to remove the desired components. The tool and facility requirements, emergency procedures, and training requirements are investigated.

The experiment procedures and requirements are defined for a particular assembly, the infrared horizon sensor on the Nimbus-A meteorological satellite. Three major subtasks, performed in space, were defined: (1) penetration for recovery of component, (2) removal and initial evaluation, and (3) storage and transfer to ground. These tasks require a total time of 13 hours. The major equipments required for leaving the spacecraft, removing the component, and getting back into the spacecraft are given in Table 4.

Table 4

EQUIPMENT REQUIRED FOR COMPONENT REMOVAL

Item	Approximate Volume (cubic inches)	Approximate Weight (pounds)
Component Removal Kit	2300	48
Component and Container	100	6
Biopack/Maneuvering Unit (3)	20,100	468
Emergency Oxygen Supply (2)	3020	80
	25,520	602

The ground tests and evaluation procedures are standard; the requirements include an analysis pertaining to the in-space environment, and the usual precautionary measures regarding contamination.

The problem areas potentially affecting the successful completion of Experiment 4 center around the extra-vehicular activities required to remove the component without damage or contamination.

General Experiments

Experiment 5, "Calibration of a Low-G Sensor." — This experiment proposes two methods to calibrate the Bell Aerosystems Corporation MESA accelerometer aboard an AES spacecraft to a significantly greater accuracy than possible on earth. One method uses a centrifuge attached to the spacecraft, and will provide data in the range of 10^{-8} G. The second method, more complicated, places the accelerometer aboard a subsatellite within an evacuated chamber of the spacecraft. It promises data in the 10^{-10} G range. The equipment estimates are shown in Tables 5 and 6.

The problems which need further analysis are:

- The accuracy of knowing the center-of-mass of the spacecraft (desire 1/10 foot) during the test period, when using the centrifuge method

- The magnitude and effect of random vibrations and disturbances induced in the spacecraft as the result of crew and machinery motions during the test period, when using the centrifuge method.

Experiment 6, "Long-Boom Dynamics." — This experiment proposes a series of tests to evaluate the feasibility of using a 30- to 40-foot boom of lightweight, somewhat flexible construction (e.g., modified DeHavilland Booms) to move large masses in space, much as a crane or boom is used on earth. The experiment would use various control system/operator configurations to test the operator's ability to precisely position test loads. The equipment requirements are given in Table 7.

Table 5

EQUIPMENT REQUIRED FOR CENTRIFUGE METHOD

Number of Units	Name/Description	Weight (pounds)	Volume (cubic inches)	Operating Power (watts)
1	Centrifuge	5.00	37.7	—
1	Servo motor (Inland T-1321)	0.30	0.37	10.0 (dc)
1	Rate-integrating gyro (Mig GG87A)	1.20	12.56	12.0 (ac)
1	MESA-I Accelerometer	0.66	18.95	6.0 (dc)
	electronics	3.2	103.0	
1	Amplifier network	0.20	1.0	1.0 (dc)
1	Counter	0.45	8.25	2.0 (dc)
1	Miscellaneous electronics and switches	0.75	12.0	1.0 (dc)
		11.76		20.0 (dc) 12.0 (ac)

Table 6

EQUIPMENT REQUIRED FOR SUBSATELLITE METHOD

Number of Units	Name/Description	Weight (pounds)	Volume* (cubic inches)	Operating* Power (watts — dc)
1	Zero-drag vehicle strut	10.0	9000	
1	MESA-I accelerometer	0.66	8.95	6.0
	electronics	0.2	1.0	
2	Cold-gas jets	0.1	1.25	2.0
1	Tank & plumbing	2.0	35.0	
1	Pressure regulator	1.5	1.0	
1	Optics	1.0	1.5	2.0
1	Sun sensor	0.005	0.0315	
1	Telemetry link	0.7	8.0	4.0
1	Control logic	0.1	9.0	
1	Release mechanism	2.0	72.0	
1	Battery	1.5	24.0	
		18.265		14.0

*Approximate values

Table 7

EQUIPMENT REQUIRED FOR LONG-BOOM EXPERIMENTS

Equipment	Weight (pounds)	Volume (cubic feet)	Power (watts)
Boom and deployment device (including end clamp)	50	1.5	30
Boom trunions and control system	50	2.0	
Load (basic module with FM receiver, plus four 100-pound ballasts)	500	1.1	
Target and transponder	20	0.5	
Cameras	16	0.35	
	636	5.45	30

This experiment needs only the development of a boom system aboard the ORL to proceed.

Experiment 7, "Ullage Control for Fuel Transfer." — This experiment seeks to determine, by scale-model tests, the magnitude of acceleration forces required to obtain positive ullage control in fluids in space. This basic information can then be applied, with appropriate scaling, to the design of fuel transfer equipment required for large-scale operations. The equipment required is listed in Table 8.

The experiment apparatus is small and lightweight, and has no particular problems to be solved.

Experiment 8, "Extra-Vehicular Patching Techniques." — This experiment proposes to evaluate different methods of patching punctures in the external shell of the spacecraft. These punctures could result from accidents during docking or extravehicular maneuvers, or could be caused by meteoroids. A controlled experiment is obtained by using 25 cells with pre-formed punctures. Various patches would be applied to these cells, which would be mounted in a test rack in the spacecraft; then, the effectiveness of the seal obtained is evaluated, and any application problems noted.

Table 9 lists the required equipment. No problems are anticipated in the design of this experiment.

Table 8

EQUIPMENT REQUIRED FOR ULLAGE CONTROL EXPERIMENT

Item Description	Rating (psia)	Weight (pounds)
Plexiglas transfer tank (6"×24"×0.060")	25	3.0
Plexiglas receiver tank (7-1/2"×15"×0.060")	25	2.6
Aluminum MMH bottle (7" dia. ×0.030" sphere)	35	2.0
Two 28-Vdc, 57-watt variable-speed, reversible transfer pumps (0.7 psi at 0.133 lb. MMH/sec)	*	2.0
Aluminum nitrogen bottle (5" dia. ×0.030" sphere)	500	2.0
Two 26-Vdc, 85-watt, variable-speed, variable-torque rotation motors	*	3.0
One 28-Vdc, 57-watt, variable-speed, variable-torque, vapor/liquid separator	*	1.5
Telemetry and control system	*	12.0
Valves, fittings, piping, and wiring	*	6.0
Instrumentation system	*	9.0
Thermal control system	*	3.0
Platform and attachment structure		7.0
Bearings, pulleys, and seals		2.0
MMH test field		26.0
Nitrogen		0.1
		81.2

*To be determined.

Table 9

EQUIPMENT REQUIRED FOR EXTRA-VEHICULAR PATCHING

Equipment	Weight (pounds)	Volume (cubic feet)
Experiment panel and mounting (25 cells):		
(a) extra-vehicular panel	10.8	0.52
(b) control panel	10.5	0.41
Tools and patches (two sets of patches)	30.8	0.25
Astronaut constraint device	22 (10)*	0.50
Camera, video and lighting equipment	69.0	1.0
Photographic equipment	21.0	0.30
Vehicle reinforcement	20.0	—
Cabin-located instrumentation	30.0	1.5
	213.3	4.48

*To be determined

Significant Results

The details of the design of the eight engineering experiments are contained in "Analysis and Preliminary Design of Engineering Experiments for Manned Earth-Orbital Missions," IBM Report No. 65-928-65, August 1965.

ALLOCATION OF RESOURCES IN AN ORL

This portion of the study produced the basis for a new approach to the space-laboratory/experiment-resource allocation problem. Conception of the resource parameters as vector quantities in a hyper space makes it possible to approach this problem using existing operations-research methods. Because of the unavailability of the actual spacecraft and experiment data necessary to ascertain the practicality and usefulness of the techniques, evaluation (or modification) of the proposed methods had to be deferred. The techniques are completely described in "Allocation of Scarce Resources Aboard an Orbital Laboratory,"IBM Report No. 65-928-66, August 1965.

SUGGESTED ADDITIONAL EFFORT

This study has pointed out the lack of knowledge pertaining to the long-term effects of the space environment on materials, and has shown the need for such data. Due to the limitations of simulation facilities, trustworthy data can only be obtained by examination of material specimens exposed to the actual environment (i.e., on satellites). Therefore, IBM recommends that the following concurrent programs be initiated:

- Mission and configuration analysis leading to the attainment of a satellite retrieval capability early in the AES Earth-Orbital Flight Program

- Preliminary design of a family of materials technology satellites, which record their environment and then are returned from orbit by the satellite retrieval technique.

ABSTRACT

This report summarizes the approach taken and the results obtained by the IBM Corporation in performing the study of an "Engineering Research Experiments Program for Manned Earth - Orbital Missions," Contract NAS 1-4667. Reports detailing this study are listed in the Foreword of this report.